



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Deletion of the myeloid endothelin-B receptor confers long-term protection from angiotensin II-mediated renal, retinal & vascular injury

Citation for published version:

Guyonnet, L, Czopek, A, Farrah, TE, Baudrie, V, Bonnin, P, Chipont, A, Lenoir, O, Sennlaub, F, Webb, D, Kluth, D, Bailey, M, Tharaux, P-L & Dhaun, N 2020, 'Deletion of the myeloid endothelin-B receptor confers long-term protection from angiotensin II-mediated renal, retinal & vascular injury', *Kidney International*.
<https://doi.org/10.1016/j.kint.2020.05.042>

Digital Object Identifier (DOI):

[10.1016/j.kint.2020.05.042](https://doi.org/10.1016/j.kint.2020.05.042)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher's PDF, also known as Version of record

Published In:

Kidney International

General rights

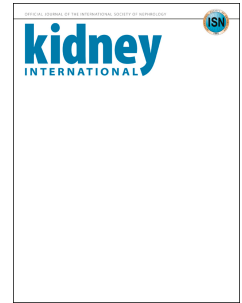
Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



Journal Pre-proof



Deletion of the myeloid endothelin-B receptor confers long-term protection from angiotensin II-mediated kidney, eye and vessel injury.

Léa Guyonnet, Alicja Czopek, Tariq E. Farrah, Véronique Baudrie, Philippe Bonnin, Anna Chipont, Olivia Lenoir, Florian Sennlaub, Christophe Roubéix, David J. Webb, David C. Kluth, Matthew A. Bailey, Pierre-Louis Tharaux, Neeraj Dhaun

PII: S0085-2538(20)30690-6

DOI: <https://doi.org/10.1016/j.kint.2020.05.042>

Reference: KINT 2157

To appear in: *Kidney International*

Received Date: 19 March 2020

Revised Date: 25 April 2020

Accepted Date: 7 May 2020

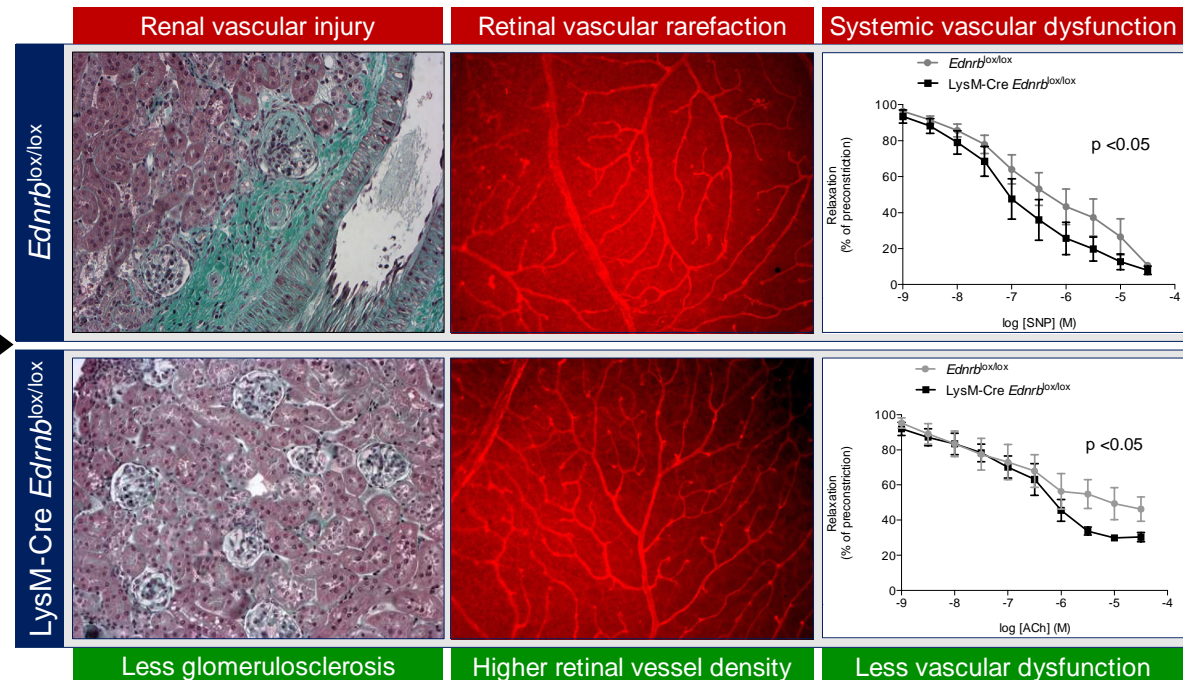
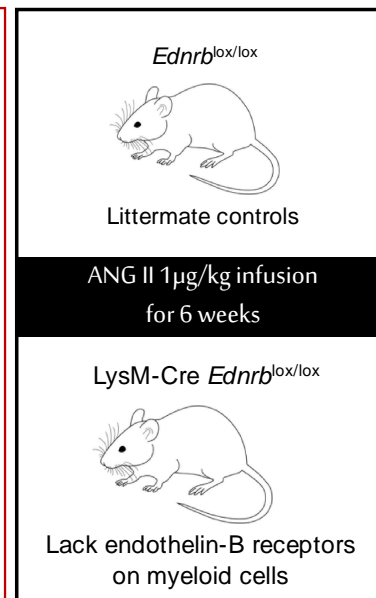
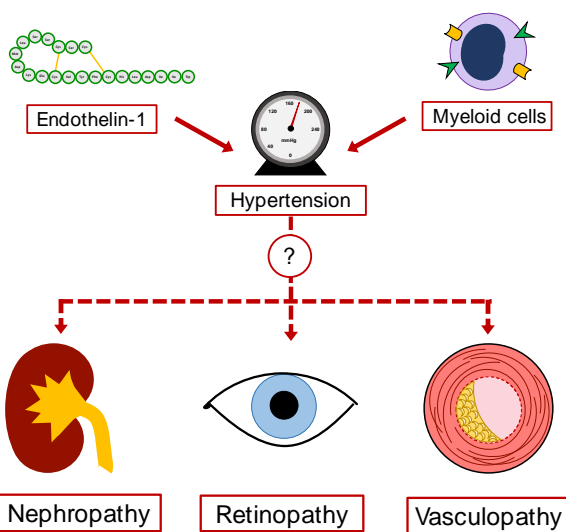
Please cite this article as: Guyonnet L, Czopek A, Farrah TE, Baudrie V, Bonnin P, Chipont A, Lenoir O, Sennlaub F, Roubéix C, Webb DJ, Kluth DC, Bailey MA, Tharaux PL, Dhaun N, Deletion of the myeloid endothelin-B receptor confers long-term protection from angiotensin II-mediated kidney, eye and vessel injury., *Kidney International* (2020), doi: <https://doi.org/10.1016/j.kint.2020.05.042>.

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Copyright © 2020, Published by Elsevier, Inc., on behalf of the International Society of Nephrology.

Deletion of the myeloid endothelin-B receptor confers long-term protection from angiotensin II-mediated kidney, eye and vessel injury.

Mechanisms of target organ damage are unclear



CONCLUSION:

Myeloid ET_B receptor deficiency protects from end-organ injury associated with sustained ANG II administration

[QUERY TO AUTHOR: title and abstract rewritten by Editorial Office – not subject to change]

Deletion of the myeloid endothelin-B receptor confers long-term protection from angiotensin II-mediated kidney, eye and vessel injury.

Léa Guyonnet¹

Alicja Czopek²

Tariq E Farrah²

Véronique Baudrie¹

Philippe Bonnin³

Anna Chipont¹

Olivia Lenoir¹

Florian Sennlaub⁴

Christophe Roubeix⁴

David J Webb²

David C Kluth²

Matthew A Bailey^{2‡}

Pierre-Louis Tharaux^{1‡}

Neeraj Dhaun^{1,2‡}

[‡] *Joint last authors*

¹Paris Cardiovascular Research Centre - PARCC, Institut National de la Santé et de la Recherche Médicale (INSERM), Paris, France.

²University/BHF Centre of Research Excellence, University of Edinburgh, The Queen's Medical Research Institute, 47 Little France Crescent, Edinburgh, UK.

³INSERM U1275 & Physiologie Clinique, Hôpital Lariboisière, Université de Paris, France

⁴Institut National de la Santé et de la Recherche Médicale, Institut de la Vision, Paris, France.

Correspondence to: Dr Neeraj Dhaun (bean.dhaun@ed.ac.uk)

Prof Pierre-Louis Tharaux (pierre-louis.tharaux@inserm.fr)

No of words in manuscript: 4,522 Tables: 1 supplementary Figures: 9

Running title: Myeloid ET_B receptors & angiotensin-mediated injury

Abstract

The endothelin system may be an important player in hypertensive end-organ injury as endothelin-1 increases blood pressure and is pro-inflammatory. The immune system is emerging as an important regulator of blood pressure and we have shown that the early hypertensive response to angiotensin-II infusion was amplified in mice deficient of myeloid endothelin-B (ET_B) receptors (LysM-Cre*Ednrblox/lox*). Hypothesizing that these mice would display enhanced organ injury, we gave angiotensin-II to LysM-Cre*Ednrblox/lox* and littermate controls (*Ednrblox/lox*) for six weeks. Unexpectedly, LysM-Cre*Ednrblox/lox* mice were significantly protected from organ injury, with less proteinuria, glomerulosclerosis and inflammation of the kidney compared to controls. In the eye, LysM-Cre*Ednrblox/lox* mice had fewer retinal hemorrhages, less microglial activation and less vessel rarefaction. Cardiac remodeling and dysfunction were similar in both groups at week six but LysM-Cre*Ednrblox/lox* mice had better endothelial function. Although blood pressure was initially higher in LysM-Cre*Ednrblox/lox* mice, this was not sustained. A natriuretic switch at about two weeks, due to enhanced ET_B signaling in the kidney, induced a hypertensive reversal. By week six, blood pressure was lower in LysM-Cre*Ednrblox/lox* mice than in controls. At six weeks, macrophages from LysM-Cre*Ednrblox/lox* mice were more anti-inflammatory and had greater phagocytic ability compared to the macrophages of *Ednrblox/lox* mice. Thus, myeloid cell ET_B receptor signaling drives this injury both through amplifying hypertension and by inflammatory polarization of macrophages.

Key words: hypertension; organ injury; macrophages, endothelin

Translational statement

Hypertension is the single largest contributor to the global burden of disease and to global mortality. It is a major risk factor for chronic kidney disease, atherosclerosis and retinopathy, end-organ effects with devastating consequences. Preventing this injury is the principal therapeutic goal in patients with hypertension. Our data provide novel insights into the roles the immune and endothelin systems in the hypertensive end-organ injury seen in the kidney, eye and vasculature, providing a rational basis for further investigation into the modulation of these pathways for therapeutic gain. These and other successful studies may encourage industry to take a lead in this relatively orphan area, potentially resulting in a more rational prescribing of endothelin receptor antagonists for hypertension.

Introduction

Hypertension is the biggest single contributor to the global burden of disease and to global mortality.¹ Currently, it is estimated that a quarter of the world's adult population is hypertensive, projected to reach ~30% by 2025.² Arterial hypertension is a major risk factor for atherosclerosis, coronary artery disease, stroke, and chronic kidney disease which underpin its devastating effects.³ Thus, preventing end-organ damage is the principal therapeutic goal in patients with hypertension. The last few decades have seen few advances in the treatment of hypertension and its complications. Improved understanding of the mechanisms underlying hypertensive end-organ damage might provide new therapeutic opportunities, particularly for those resistant to conventional blood pressure (BP)-lowering strategies.

In this context, animal models provide an important discovery platform.⁴ Chronic angiotensin II (ANG II) infusion is widely used to capture the cardinal features of clinical disease^{4,5} and studies extending the model beyond four weeks demonstrate stable hypertension and significant cardiac, renal and vascular injury.⁴ Earlier work shows that these are blunted by endothelin-1 (ET-1) receptor antagonism.^{6,7} Indeed, ET receptor antagonism is an emerging therapeutic option in a number of clinical conditions including chronic kidney disease⁸ and resistant hypertension.⁹ This partly reflects a hemodynamic benefit since ET-1 exerts powerful, sustained vasoconstriction¹⁰ *via* activation of endothelin-A (ET_A) receptors present on vascular smooth muscle. In addition, ET_A receptor activation is directly pro-inflammatory and pro-fibrotic so BP-independent benefits of ET-1 antagonism may also be therapeutically important.

There has been less focus given to the role of the endothelin-B (ET_B) receptor, which exerts a countervailing influence on BP. Endothelial ET_B activation causes vasodilation and activation

of ET_B in the distal renal tubule promotes natriuresis.¹¹ Additionally, the ET_B receptor plays a key role in clearing ET-1 from the circulation and curtailing its bioactivity.¹² Indeed, we recently showed that ET_B receptor-mediated clearance of ET-1 by myeloid cells protected against the early development of experimental hypertension.¹³ Other studies also point to the innate immune system, particularly macrophages, as an important modulator of the development and progression of hypertension.¹⁴⁻¹⁸ Whether this also modulates target organ injury is less clearly defined. We therefore hypothesized that targeted deletion of the mouse myeloid ET_B receptor would exaggerate hypertensive end-organ injury. In the current study we infused ANG II for 6 weeks and examined injury in the kidney, eye, heart and vasculature. Surprisingly, myeloid ET_B receptor deficiency *protected* from end-organ injury. These effects partly reflected a reduction in BP but also involved a tuning of macrophages to an anti-inflammatory phenotype. Thus, targeting the myeloid ET system may provide an attractive and novel therapeutic strategy in the context of hypertensive end-organ damage.

Results

Myeloid ET_B receptor deficiency protects from ANG II-mediated renal injury

After 6 weeks of ANG II infusion, renal excretory function was no different between mice with a myeloid-specific disruption of the *Ednrb* gene (LysM-Cre *Ednrb*^{lox/lox}) and littermate controls (mice with no expression of Cre recombinase *Ednrb*^{lox/lox}) (**Figure 1A**). *Ednrb*^{lox/lox} mice developed progressive, heavy albuminuria over this period. By contrast, LysM-Cre *Ednrb*^{lox/lox} mice displayed only a modest rise in urinary albumin excretion which did not progress between week 3 and week 6 (at 6 weeks: 564±86 vs. 139±44 g/M, $p < 0.001$, **Figure 1B**). Consistently, there was less glomerulosclerosis at 6 weeks in LysM-Cre *Ednrb*^{lox/lox} mice compared to controls (61±4 vs. 34±2%, $p < 0.0001$, **Figures 1C & 1D**). Additionally, there was a greater preservation of glomerular ultrastructure – less glomerular basement membrane thickening and podocyte foot process broadening and effacement – in LysM-Cre *Ednrb*^{lox/lox} mice compared to control mice (**Figure 1E**).

The protective effects of the myeloid ET_B receptor extended to ANG II-mediated tubular injury with LysM-Cre *Ednrb*^{lox/lox} mice demonstrating fewer tubular casts after 6 weeks of ANG II compared to *Ednrb*^{lox/lox} (**Figures 1F & 1G**). This was supported by lower cortical and medullary *Kim-1* expression in knockout mice compared to controls at 6 weeks (**Figure 1H**).

Myeloid ET_B receptor deficiency reduces ANG II-mediated renal inflammation

At baseline, there was no difference in the number of renal resident macrophages between LysM-Cre *Ednrb*^{lox/lox} and *Ednrb*^{lox/lox} mice. Six weeks of ANG II increased the number of renal macrophages to a greater extent in *Ednrb*^{lox/lox} mice than in those deficient in myeloid ET_B receptors (at 6 weeks, F4/80+ area/total area: 1.5±0.3 vs. 3.8±0.4%, $p < 0.001$, **Figure 2A**). Similarly, the number of renal T lymphocytes was no different between the two groups

at baseline and increased to a greater extent in *Edrnb*^{lox/lox} mice following 6 weeks of ANG II than in Lys M-Cre *Edrnb*^{lox/lox} mice (at 6 weeks, CD3+ area/total area: 3.2±0.6 vs. 6.9±1.1%, $p < 0.01$, **Figure 2B**).

Myeloid ET_B receptor deficiency promotes an anti-inflammatory renal environment in response to ANG II

We went on to further examine the effects of ANG II on the balance between a pro-inflammatory (*Tnfa* and *Il-6*) and anti-inflammatory (*Mrc1* and *Arg1*) environment within the kidney. At baseline, and in both cortex and medulla, *Tnfa*, *Il-6*, *Mrc1* and *Arg1* expression did not differ between LysM-Cre *Edrnb*^{lox/lox} and *Edrnb*^{lox/lox} mice (**Figures 3A- 3D**). Following 6 weeks of ANG II, cortical and medullary *Il-6* expression increased ~4-6-fold and medullary *Tnfa* ~3-fold in control mice whereas, LysM-Cre *Edrnb*^{lox/lox} mice displayed a modest increase in medullary *Il-6* but no change in *Tnfa* in either compartment (**Figures 3A & 3B**). Conversely, whereas *Edrnb*^{lox/lox} mice demonstrated no changes in cortical or medullary *Mrc1* and *Arg1* expression following ANG II, knockout mice upregulated cortical *Arg1* and medullary *Mrc1* (**Figures 3C & 3D**).

Myeloid ET_B receptor deficiency protects from ANG II-mediated retinal injury

Prolonged uncontrolled hypertension leads to the development of retinal hemorrhages and immune cell infiltration. Deletion of the ET_B receptor on myeloid cells alone significantly reduced the number of retinal hemorrhages seen following ANG II infusion by ~90% (**Figure 4A**). Six weeks of ANG II led to vessel rarefaction in the inner retina plexus in *Edrnb*^{lox/lox} mice, whereas the vessel density of LysM-Cre *Edrnb*^{lox/lox} mice was preserved (**Figure 4B**). In addition, control mice demonstrated a greater number of activated microglia in the inner retina in response to 6 weeks of ANG II compared to knockout mice (**Figure 4C**). Activated microglia exhibited a typical round shape with larger cell body and short neurites.

Myeloid ET_B receptor deficiency does not affect ANG II-mediated cardiac hypertrophy & dysfunction

Six weeks of ANG II led to changes in cardiac structure that were in keeping with the development of left ventricular hypertrophy; these did not differ between LysM-Cre $Ednrb^{lox/lox}$ and $Ednrb^{lox/lox}$ mice (data not shown). ANG II infusion led to a similar increase in heart rate (**Figure 5A**) and reduction in cardiac output (CO) (**Figure 5B**) in both groups. LysM-Cre $Ednrb^{lox/lox}$ and littermates also showed a similar reduction in left ventricular shortening fraction (**Figure 5C**).

Myeloid ET_B receptor deficiency protects from ANG II-mediated endothelial dysfunction

As expected, 6 weeks of ANG II infusion reduced renal artery blood flow by ~50% and this fall was no different between LysM-Cre $Ednrb^{lox/lox}$ and control mice (**Figure 5D**). ANG II did not affect basilar artery blood flow (**Figure 5E**) in either group. Interestingly, LysM-Cre $Ednrb^{lox/lox}$ displayed greater basilar artery vascular reactivity at baseline compared to controls (20 ± 1 vs. $11 \pm 2\%$, $p < 0.01$). Following 6 weeks of ANG II, and in keeping with the development of significant vascular dysfunction, this response was abolished in $Ednrb^{lox/lox}$ mice whereas LysM-Cre $Ednrb^{lox/lox}$ mice retained a significant, albeit reduced, basilar artery vasodilatory capacity that remained within the physiological range (10 ± 2 vs. $0 \pm 3\%$, $p < 0.05$, **Figure 5F**). In keeping with these data, whereas there were no differences in the responses of isolated mesenteric vessels from knockout and control mice to acetylcholine (endothelium-dependent) and sodium nitroprusside (endothelium-independent) vasodilation at baseline, 6 weeks of ANG II led to impairment of both but with less marked effects in myeloid ET_B receptor deficient mice compared to controls (**Figure 6**).

Myeloid ET_B receptor deficiency has a biphasic effect on long-term ANG II-mediated hypertension & promotes natriuresis

LysM-Cre *Edrnb*^{lox/lox} mice demonstrated an exaggerated BP response to ANG II during the first 2 weeks of infusion, confirming our previous work.¹³ Extending the protocol, we demonstrated that this exaggerated BP response was not sustained. Indeed, there was a reversal during weeks 3-4 such that in weeks 5 and 6, knockout mice now had a significantly lower BP compared to controls (**Figure 7A**).

Next, we examined renal salt excretion at key time points over the course of the 6-week study. Before ANG II infusion, sodium excretion was no different between genotypes. Infusion of ANG II induced an increase in natriuresis in control mice and this was sustained through the 6-week course of the study. The response was different in myeloid ET_B receptor deficient mice: the early natriuresis was blunted (**Figure 7B**), concomitant with the exaggerated hypertensive response to ANG II; by week 6, the natriuresis was significantly greater than in controls, coincident with the reversal of BP. ET_B receptors are expressed in the principal cell of the renal tubule. Activation of ET_B here inhibits the epithelial sodium channel (ENaC) to promote natriuresis. We therefore examined renal expression of the ET_B receptor and α ENaC subunit (the rate-limiting step for functional ENaC formation). Pre-ANGII, there was no difference between genotypes in the expression of either ET_B or α ENaC mRNA. At 6 weeks, control mice showed a significantly increased abundance of α ENaC mRNA in both the cortex and medulla, which was not evident in LysM-Cre *Edrnb*^{lox/lox} mice. Notably, only LysM-Cre *Edrnb*^{lox/lox} mice showed a significant increase in ET_B expression after 6 weeks of ANG II infusion (**Figure 7C**).

Myeloid ET_B receptor deficiency promotes an anti-inflammatory macrophage & neutrophil phenotype in response to ANG II

Next, we explored the effects of ANG II and myeloid ET_B receptor deficiency on macrophage and neutrophil phenotype. At baseline, there were no differences seen between macrophages from *Edrnb*^{lox/lox} or LysM-Cre *Edrnb*^{lox/lox} mice in terms of their ability to polarize to an inflammatory (M1) or anti-inflammatory (M2) phenotype, or their phagocytic ability (**Supplementary table 1**). Interestingly, after 6 weeks of exposure to ANG II, macrophages harvested from LysM-Cre *Edrnb*^{lox/lox} mice demonstrated less of an M1 phenotype and more of an M2 phenotype than macrophages from littermate controls (**Figures 8A-8C**). Knockout macrophages also displayed a greater phagocytic capacity than controls at this timepoint (**Figure 8D**). Neutrophils from *Edrnb*^{lox/lox} or LysM-Cre *Edrnb*^{lox/lox} mice did not differ at baseline in terms of cytokine production. However, after exposure to 6 weeks of ANG II neutrophils from knockout mice were less inflammatory compared to control cells (**Figures 9A & 9B**).

Discussion

Damage to the kidney, heart, eye and arteries underpins the devastating consequences of sustained hypertension. In this study we purposefully used an extended-duration ANG II infusion to model such end-organ injury with stable hypertension. In the kidney, injury to both the glomerular and interstitial compartments was apparent and the gradual development of proteinuria and glomerulosclerosis is analogous to that observed in human progressive CKD. We examined how ET-1/ET_B signaling in myeloid cells contributed to the development of organ injury. Our study had 3 main findings. First, we have demonstrated, for the first time, that activation of the myeloid ET_B receptor makes a significant contribution to renal, retinal and vascular injury induced by ANG II. Second, the injurious role of myeloid cell ET-1/ET_B signaling may reflect polarization of macrophages to a pro-inflammatory phenotype. Third, myeloid cell ET_B receptors modulate the BP response to ANG II infusion in a biphasic way, a Janus-faced role of macrophages that is relevant to progressive human disease.

Current research shows that macrophages play diverse roles in hypertension. Crowley *et al* showed that mice lacking ANG type 1 receptors on bone marrow derived cells develop exaggerated hypertension and proteinuria during ANG II infusion¹⁶ whilst Rickard *et al* studied mice with a macrophage-specific knockout of the mineralocorticoid receptor and found they were protected from deoxycorticosterone acetate (DOCA)/salt induced hypertension.¹⁷ As opposed to altering macrophage phenotype, Wenzel and colleagues elegantly depleted macrophages and found that this markedly blunted virtually all consequences of chronic ANG II infusion, including BP elevation, superoxide production, vascular dysfunction and fibrosis (some of these effects may have been due to modulation of the ET system).¹⁵ We also found that macrophages provide a buffering mechanism in the development of hypertension. The presence of a functional ET-1/ET_B signalling cascade in macrophages slowed the initial rise in BP induced by a 2-week infusion of either ET-1 or

ANG II.¹³ The hypertension induced by ANG II is partly mediated by ET-1 and we found in both models that the initial BP-lowering effect of macrophages reflected clearance of ET-1, dependent on an unblocked ET_B receptor and intact endocytosis.¹³ We now show that this ‘protective’ role of ET-1/ET_B in macrophages is not sustained. The BP differential between mice with and without macrophage ET_B receptors is lost beyond two weeks, and indeed reverses after 4 weeks of ANG II treatment. An ‘injurious’ role for macrophage ET_B ultimately emerges such that specific deletion of this receptor substantially reduces organ injury in the kidney, eye and vasculature, at least in the setting of ANG II hypertension. This remains to be confirmed in an ET-1 infusion model. Similarly, we have not yet explored whether the myeloid ET_A receptor, expressed at much lower levels than the ET_B receptor,¹³ contributes to injury progression.

By extending our examination of ANG II hypertension beyond two weeks, we highlight diverse and changing roles for macrophages in BP regulation. The hypertensive reversal after 3-4 weeks was associated with marked improvement in the natriuretic response. Our data point to a mechanism involving increased tubular ET-1/ET_B signalling and down-regulation of ENaC mediated sodium re-absorption in the distal nephron. Moreover, the magnitude of the natriuresis is large and it is likely that transporters in other segments of the nephron are downregulated. Defining how the nephron functionally remodels sodium transport could be assessed by examining the natriuretic response to a panel of diuretics¹⁹ and is a future direction of our research. Similarly, how deletion of myeloid cell ET_B receptor leads to upregulation of the same system in the principal cell is currently unclear. Recent studies show that renal epithelial cells produce chemokines to orchestrate intrarenal distribution of monocyte-derived cells.^{20,21} Whether our data uncover direct ‘myelo-tubular’ crosstalk within the normal operation of the ET-1 pathway requires further investigation.

Chronic ANG II infusion also promotes renal T-cell and macrophage infiltration, shown here and by others.^{22,23} This infiltration was substantially reduced by myeloid ET_B deficiency, which also shifted the renal cortico-medullary environment from an inflammatory to a more anti-inflammatory one. Together these suggest that the macrophage ET-1/ET_B signalling system operates to promote inflammation and injury in the long-term. Certainly, sustained ANG II treatment upregulates the vascular and renal ET system.^{6,7} We have previously shown that macrophages display ET_B-dependent chemokinesis towards ET-1. It is plausible that the increase in renal macrophages seen after 6 weeks of ANG II infusion reflects recruitment of monocytes to the kidney in chemokinetic response to a high systemic-intrarenal ET gradient. Moreover, effective ET_B blockade disrupts the myeloid ET_B sensing mechanism, leading to fewer circulating monocytes transitioning to the kidneys. Others have explored renal inflammation and the contribution that the ET system makes to this. Boesen *et al.* showed that during a 2-week infusion of ANG II in mice, ET_A receptor activation mediated a BP-independent increase in renal cortical T-cells whereas medullary T-cell and cortico-medullary macrophage infiltration was BP-dependent.²⁴ Similarly, in a model of diabetic nephropathy, treatment with an ET_A antagonist reduced renal macrophage infiltration and fibrosis.²⁵ In both studies ET receptor blockade was given systemically and so the specific cell mediating the beneficial effects was unclear.

Although no different at baseline, macrophages from myeloid ET_B knockout mice taken after six weeks of exposure to ANG II displayed a more M2/anti-inflammatory and reparative phenotype than those from littermate control mice which showed a more M1/inflammatory one. The ability of ANG II to promote an inflammatory macrophage phenotype is well recognized.²⁶⁻²⁸ However, its exact mechanism remains unclear. Our data suggest an interaction between macrophage ANG II receptors and ET_B to promote this phenotypic switch. ANG II-mediated hypertension and end-organ injury are to a large extent mediated by

an upregulation of the ET system. Thus, ET receptor antagonism is able to abrogate these effects.^{6,7} However, previous studies have not explored the type and location of the ET receptor involved. Our novel findings support a key role for macrophage ET_B receptors in mediating these effects.

Few recent studies have explored the effects of ANG II-mediated hypertension on the eye. Retinal hemorrhages and vascular loss are characteristic of hypertensive eye injury and both were seen here. They were reduced with myeloid ET_B deficiency as was retinal inflammation assessed by microglial activation. ANG II contributes to a number of eye disorders including diabetic retinopathy, glaucoma and retinopathy of prematurity.²⁹ In retinopathy of prematurity, blockade of ANG type 1 receptors promotes the re-establishment of normal vessel growth and reduces microglia recruitment.³⁰ These effects are similar to those seen here and so targeting the myeloid ET system may provide a novel direction for future studies in these areas. Indeed, one study in diabetic mice showed an improvement in the retinal vascular network and reduced pericyte loss with the ET_A antagonist, atrasentan.³¹

As expected, chronic ANG II infusion resulted in both endothelium-dependent and endothelium-independent dysfunction. This injury is a result of damage to both the vascular endothelial cell and underlying smooth muscle cell. This was ameliorated by myeloid ET_B receptor deficiency. The mechanisms for this protection probably relate in part to the shift in macrophage phenotype we observed in response to ANG II between the two groups of mice. It is well recognized that inflammatory macrophages contribute to endothelial dysfunction.^{15,32} Phagocytosis also contributes to inflammation resolution through removal of cell debris.³³ Here, phagocytic capacity of knockout macrophages was greater than in controls and so this may also explain the differential effects seen in the kidneys, eye and vasculature.

In the current study, the magnitude of the anti-proteinuric and anti-fibrotic effects of effective myeloid ET_B receptor blockade (~40-60%) is similar to that seen with ET receptor antagonists. As both selective ET_A and mixed ET_{A/B} receptor antagonists are available in the clinic the addition of our own data to these earlier studies suggest that both approaches may be beneficial in reducing ANG II-mediated renal damage which is the one of the main mechanisms in the development and progression of CKD. Consistent with this, the recent SONAR study demonstrated the efficacy of atrasentan, an endothelin-A antagonist, in slowing diabetic CKD progression when added to renin-angiotensin system blockade.⁸

In summary, our study has identified a novel role for the myeloid ET system in mediating ANG II-associated injury in the eye, kidney and vasculature. The long-term protective effects of deleting the myeloid ET_B receptor were only resolved by extending the duration of our experiment, highlighting the importance of 'time' as a factor when modeling chronic, progressive human disorders. The protection ultimately conferred by myeloid ET_B receptor depletion may be partly hemodynamic, reflecting the lowering of BP following natriuresis. Our data also indicate that reprogramming of macrophage and/or neutrophil phenotype and function is likely to be important. We cannot currently discriminate the relative contributions of macrophages and neutrophils to this protective phenotype, a limitation of the study requiring further work. Moreover, we cannot yet clearly map across to humans the biphasic BP response to myeloid ET_B receptor deletion. We previously reported that cyclophosphamide therapy, depleting circulating monocytes and tissue macrophages (as well as T- and B-cells), increased BP in patients with vasculitis,¹³ at least initially and a longer study is now needed. This is relevant, since targeting the immune system is recognized as an effective treatment for hypertension in man as seen in studies using IL6 antagonism³⁴ and immunisation against ANG II.³⁵ Similarly, macrophage cell therapy is currently being explored as an anti-inflammatory approach in a number of disease states.³⁶⁻³⁸ Combining

these with newer monoclonal antibodies that specifically target ET_A and ET_B³⁹ might allow the current data to be explored in the clinical setting.

Methods (please also see Supplemental material)

Angiotensin II (ANG II)-mediated end-organ damage

Mice were infused ANG II (1µg/kg/min, SigmaAldrich) subcutaneously using osmotic mini pumps (Alzet, model 2006) for a period of six weeks. Animals were fed a high-salt diet (NaCl 3%) and had free access to food and water. BP was measured in conscious, unrestrained mice using a radio-telemetry system (PA-C10 and Dataquest software, Data Sciences International). Recordings were obtained every 15min for 60s; daytime was defined as 0700 - 1900 and nighttime as 1900 - 0700.

Assessment of renal function and albuminuria

Blood urea nitrogen (BUN) and urinary creatinine concentrations were quantified spectrophotometrically by colorimetric methods. Urinary albumin was measured with a specific ELISA assay (Cusabio, CSB-E13878m).

Renal histopathology and immunohistochemistry

Kidneys were immersed in 10% formalin and embedded in paraffin. 4mm sections were processed for histopathology or immunohistochemistry. Glomerulosclerosis was defined by focal and segmental consolidation of the tuft by increased extracellular matrix, obliterating the glomerular capillary lumen. For assessment of glomerulosclerosis, an examiner blinded to the experimental conditions assessed the % of glomeruli showing glomerulosclerosis with at least 50 glomeruli examined per field. For immunohistochemistry, paraffin embedded sections were stained with the following primary antibodies: rabbit anti-CD3 (DAKO, A 0452, 1:200), rat anti-F4/80 (AbDSerotec, MCA497, 1:500). CD3 and F4/80 staining were exposed with Histofine reagent (Nichirei Biosciences, 414141F) and color formation stopped by washing in PBS. Slides were then counterstained with hematoxylin. Photomicrographs

were taken with an Axiophot Zeiss photomicroscope (Jena, Germany). Quantification of CD3 and F480 staining was performed using ImageJ software.

Electron microscopy: Sections of renal cortex were fixed in Trump's solution (EMS, 11750) and embedded in Araldite M (Sigma Aldrich, 10951). Ultrathin sections were counter-stained with uranyl acetate and lead citrate and examined with a transmission electron microscope (JEM, JEOL 1011, Peabody, MA, USA).

Assessment of retinal injury

After enucleation, eyes were fixed in 4% paraformaldehyde for 30min at room temperature. After washing in PBS, and removal of the cornea and lens, the retina was dissected from the retinal pigment epithelium/choroid/sclera. Retinas were incubated overnight with primary antibodies (lectin Alexa conjugated, 1:100, Invitrogen; rabbit anti-Iba1, 1:400, Wako, USA) in PBS supplemented with 0.5% Triton X-100, followed by incubation with appropriate Alexa-coupled secondary antibodies (Life Technologies). Retinas were flat-mounted and viewed with a fluorescence microscope (DM5500B, Leica, France). Vascular network and activated Iba1+ cell density were calculated from an average of 8 images/animal (4/retina). Vascular network density was obtained using NeuronJ plugin on ImageJ software.

Non-invasive ultrasound assessment of cardiac, renal and cerebral hemodynamics

Ultrasound examination was carried out under isoflurane anesthesia using an echocardiograph (Acuson S3000; Siemens®, Erlangen, Germany) equipped with a 14MHz linear transducer (14L5 SP). Mice were placed on a heating blanket (38°C) to avoid hypothermia.

Cardiac parameters and cardiac output (CO): A parasternal long-axis B-mode image was used to measure CO using the mean of three successive measurements. Heart dimensions measured, in both systole and diastole, included left ventricular posterior wall thickness, left

ventricular internal diameter, and inter-ventricular septum thickness. Heart rates were obtained with an electrocardiogram.

Renal artery blood flow velocity (BFV): A pulsed Doppler sample gate was placed on the longitudinal axis of the right renal artery and the pulsed Doppler spectrum was recorded. Time-averaged mean BFV was calculated with correction of the angle between the long axis of each vessel and the Doppler beam.

Cerebral vasoreactivity: A horizontal B-mode image at the skull base allowed imaging of the basilar trunk and both internal carotid arteries. Color Doppler mode was activated and the basilar trunk with the circle of Willis were drawn and localized on the screen by their color-coded blood flow. A pulsed Doppler sample gate was placed on the longitudinal axis of the basilar trunk and the pulsed Doppler spectrum was recorded by a masked operator. Vasoreactivity was quantified as the percentage increase in mean blood flow velocity (mBFV) after 5min inhalation of 16% O₂/5% CO₂/79% N₂ compared to mBFV on ambient air.⁴⁰

Ex vivo myography

This is described in detail elsewhere.⁴¹ In brief, 2mm segments of aorta and second order mesenteric arteries were mounted in a multi-myography system (610M, Danish Myo Technology, Denmark) containing physiological salt solution aerated at 37°C with 95% O₂/5% CO₂. In all studies vessel viability was first confirmed by a contractile response on addition of 80mM KCl, repeated three times. Vessel contractility was then assessed by cumulative concentration-response curves to phenylephrine (PE; 1nM-3μM), noradrenalin (1nM-3μM) and ET-1 (1pM-30nM) and we selected a concentration that produced 80% maximum contraction for each individual vascular ring. To assess vasodilator capacity, vessels were pre-constricted with PE and cumulative concentration curves were obtained to acetylcholine (1nM-3μM) and sodium nitroprusside (1nM-3μM). At least 30min washout was allowed between drugs. Results are presented as percentage of a maximal response.

In vitro culture of peritoneal macrophages & bone marrow derived neutrophils

Freshly isolated peritoneal macrophages were plated in 6-well plates at a density of 5×10^5 cells/ 3.8 cm^2 in RPMI 1640 culture medium supplemented with 10% fetal calf serum and 1% penicillin/streptomycin (Life Technologies, 15140–122) and left to adhere for 24h. Cells were then incubated with LPS/INF γ (100ng/ml/10ng/ml, Sigma-Aldrich) or IL4/IL13 (10ng/ml for both, Invitrogen) for 24h. Bone marrow derived neutrophils were isolated and cultured *in vitro* as previously described.⁴² Cells were then incubated with LPS (100ng/ml, Sigma-Aldrich) for 24h.

Cell culture supernatants were removed and frozen immediately at -80°C until analysis. IL1 β , IL6 and TNF α were determined using ELISA (R&D Systems) according to the manufacturer's instructions. Samples were analysed in duplicate at 450nm with wavelength correction at 570nm (Synergy HT BioTEK). Concentrations were calculated from a standard curve using a second order (quadratic) regression analysis. To assess phagocytic ability, macrophages were incubated with fluorescent beads (10:1 ratio) for 60 min. Cells were vigorously washed and detached from the plates prior to quantification of phagocytosis by flow cytometry.

Author contributions: PLT and ND designed the study and provided funding; LG, AC, TEF, VB, PB, AC OL, FS and CR performed the experiments and carried out analyses; DJW, DCK, MAB and ND wrote the manuscript; all authors provided approval for the final manuscript.

Funding: TF is supported by a Clinical Research Training Fellowship from the *Medical Research Council* (MR/R017840/1). ND was supported by a *British Heart Foundation* Intermediate Clinical Research Fellowship (FS/13/30/29994) (ND). PLT is supported by the Institut National de Santé et de la Recherche Médicale.

Disclosures: None declared.

Supplementary material

Supplemental table 1

Supplemental methods

Supplementary information is available on *Kidney International's* website

References

1. Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012;380:2224-60.
2. Kearney PM, Whelton M, Reynolds K, Muntner P, Whelton PK, He J. Global burden of hypertension: analysis of worldwide data. *Lancet* 2005;365:217-23.
3. Poulter NR, Prabhakaran D, Caulfield M. Hypertension. *Lancet* 2015;386:801-12.
4. Lerman LO, Kurtz TW, Touyz RM, et al. Animal Models of Hypertension: A Scientific Statement From the American Heart Association. *Hypertension* 2019:HYP00000000000000090.
5. Galis ZS, Thrasher T, Reid DM, Stanley DV, Oh YS. Investing in high blood pressure research: a national institutes of health perspective. *Hypertension* 2013;61:757-61.
6. Rajagopalan S, Laursen JB, Borthayre A, et al. Role for endothelin-1 in angiotensin II-mediated hypertension. *Hypertension* 1997;30:29-34.
7. Moreau P, d'Uscio LV, Shaw S, Takase H, Barton M, Luscher TF. Angiotensin II increases tissue endothelin and induces vascular hypertrophy. Reversal by ET_A-receptor antagonist. *Circulation* 1997;96:1593-7.
8. Heerspink HJL, Parving HH, Andress DL, et al. Atrasentan and renal events in patients with type 2 diabetes and chronic kidney disease (SONAR): a double-blind, randomised, placebo-controlled trial. *Lancet* 2019;393:1937-1947. doi: 10.1016/S0140-6736(19)30772-X.
9. Available at:
<https://clinicaltrials.gov/ct2/show/NCT02603809?term=act-132577&rank=6>.

10. Dhaun N, Webb DJ. Endothelins in cardiovascular biology and therapeutics. *Nat Rev Cardiol* 2019;16:491-502. doi: 10.1038/s41569-019-0176-3.
11. Dhaun N, Goddard J, Webb DJ. The endothelin system and its antagonism in chronic kidney disease. *J Am Soc Nephrol* 2006;17:943-55.
12. Dhaun N, Pollock DM, Goddard J, Webb DJ. Selective and mixed endothelin receptor antagonism in cardiovascular disease. *Trends Pharmacol Sci* 2007;28:573-9.
13. Czopek A, Moorhouse R, Guyonnet L, et al. A novel role for myeloid endothelin-B receptors in hypertension. *Eur Heart J* 2019;40:768-84.
14. Machnik A, Neuhofer W, Jantsch J, et al. Macrophages regulate salt-dependent volume and blood pressure by a vascular endothelial growth factor-C-dependent buffering mechanism. *Nature Med* 2009;15:545-52.
15. Wenzel P, Knorr M, Kossmann S, et al. Lysozyme M-positive monocytes mediate angiotensin II-induced arterial hypertension and vascular dysfunction. *Circulation* 2011;124:1370-81.
16. Crowley SD, Song YS, Sprung G, et al. A role for angiotensin II type 1 receptors on bone marrow-derived cells in the pathogenesis of angiotensin II-dependent hypertension. *Hypertension* 2010;55:99-108.
17. Rickard AJ, Morgan J, Tesch G, Funder JW, Fuller PJ, Young MJ. Deletion of mineralocorticoid receptors from macrophages protects against deoxycorticosterone/salt-induced cardiac fibrosis and increased blood pressure. *Hypertension* 2009;54:537-43.
18. Wenzel P. Monocytes as immune targets in arterial hypertension. *Br J Pharmacol* 2018;176:1966-1977. doi: 10.1111/bph.14389.
19. Hunter RW, Craigie E, Homer NZ, Mullins JJ, Bailey MA. Acute inhibition of NCC does not activate distal electrogenic Na⁺ reabsorption or kaliuresis. *Am J Physiol* 2014;306:F457-67.

20. Berry MR, Mathews RJ, Ferdinand JR, et al. Renal Sodium Gradient Orchestrates a Dynamic Antibacterial Defense Zone. *Cell* 2017;170:860-74 e19.
21. Stewart BJ, Ferdinand JR, Young MD, et al. Spatiotemporal immune zonation of the human kidney. *Science* 2019;365:1461-6.
22. Barhoumi T, Kasal DA, Li MW, et al. T regulatory lymphocytes prevent angiotensin II-induced hypertension and vascular injury. *Hypertension* 2011;57:469-76.
23. Zhang JD, Patel MB, Song YS, et al. A novel role for type 1 angiotensin receptors on T lymphocytes to limit target organ damage in hypertension. *Circ Res* 2012;110:1604-17.
24. Boesen EI, Krishnan KR, Pollock JS, Pollock DM. ETA activation mediates angiotensin II-induced infiltration of renal cortical T cells. *J Am Soc Nephrol* 2011;22:2187-92.
25. Sasser JM, Sullivan JC, Hobbs JL, et al. Endothelin A receptor blockade reduces diabetic renal injury via an anti-inflammatory mechanism. *J Am Soc Nephrol* 2007;18:143-54.
26. Hahn AW, Jonas U, Buhler FR, Resink TJ. Activation of human peripheral monocytes by angiotensin II. *FEBS Lett* 1994;347:178-80.
27. Yamamoto S, Yancey PG, Zuo Y, et al. Macrophage polarization by angiotensin II-type 1 receptor aggravates renal injury-acceleration of atherosclerosis. *Arterioscler Thromb Vasc Biol* 2011;31:2856-64.
28. Ma LJ, Corsa BA, Zhou J, et al. Angiotensin type 1 receptor modulates macrophage polarization and renal injury in obesity. *Am J Physiol* 2011;300:F1203-13.
29. Fletcher EL, Phipps JA, Ward MM, Vessey KA, Wilkinson-Berka JL. The renin-angiotensin system in retinal health and disease: Its influence on neurons, glia and the vasculature. *Progr Retin Eye Res* 2010;29:284-311.

30. Deliyanti D, Miller AG, Tan G, Binger KJ, Samson AL, Wilkinson-Berka JL. Neovascularization is attenuated with aldosterone synthase inhibition in rats with retinopathy. *Hypertension* 2012;59:607-13.
31. Chou JC, Rollins SD, Ye M, Batlle D, Fawzi AA. Endothelin receptor-A antagonist attenuates retinal vascular and neuroretinal pathology in diabetic mice. *Invest Ophthalmol Vis Sci* 2014;55:2516-25.
32. Wenzel P, Rossmann H, Muller C, et al. Heme oxygenase-1 suppresses a pro-inflammatory phenotype in monocytes and determines endothelial function and arterial hypertension in mice and humans. *Eur Heart J* 2015;36:3437-46.
33. Gordon P, Okai B, Hoare JJ, Erwig LP, Wilson HM. SOCS3 is a modulator of human macrophage phagocytosis. *J Leuk Biol* 2016;100:771-80.
34. Kapoor S. Interleukin-6 antagonists for the management of hypertension. *Hypertension* 2007;49:e18; author reply e9.
35. Tissot AC, Maurer P, Nussberger J, et al. Effect of immunisation against angiotensin II with CYT006-AngQb on ambulatory blood pressure: a double-blind, randomised, placebo-controlled phase IIa study. *Lancet* 2008;371:821-7.
36. Chernykh ER, Shevela EY, Starostina NM, et al. Safety and Therapeutic Potential of M2 Macrophages in Stroke Treatment. *Cell Transplant* 2016;25:1461-71.
37. Available at:
<https://www.clinicaltrials.gov/ct2/show/NCT03337165?term=macrophage+cell+therapy&draw=10&rank=52>.
38. Chen T, Cao Q, Wang Y, Harris DCH. M2 macrophages in kidney disease: biology, therapies, and perspectives. *Kidney Int* 2019;95:760-73.
39. Davenport P, Hyndman K, Dhaun N, et al. Endothelin. *Pharmacol Rev* 2016;68:357-418. doi: 10.1124/pr.115.011833.

40. Poittevin M, Bonnin P, Pimpie C, et al. Diabetic microangiopathy: impact of impaired cerebral vasoreactivity and delayed angiogenesis after permanent middle cerebral artery occlusion on stroke damage and cerebral repair in mice. *Diabetes* 2015;64:999-1010.
41. Miller MR, Borthwick SJ, Shaw CA, et al. Direct impairment of vascular function by diesel exhaust particulate through reduced bioavailability of endothelium-derived nitric oxide induced by superoxide free radicals. *Environ Health Perspec* 2009;117:611-6.
42. Rozman S, Yousefi S, Oberson K, Kaufmann T, Benarafa C, Simon HU. The generation of neutrophils in the bone marrow is controlled by autophagy. *Cell Death Differ* 2015;22:445-56.

Figure legends***Figure 1: Specific deletion of Ednrb from myeloid cells protects from ANG II-mediated renal injury***

(A) Blood urea nitrogen concentration at 6 weeks, (B) urinary albumin excretion and (C) glomerulosclerosis at 6 weeks in *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice following ANG II. (D) Representative images of Masson's trichrome-stained kidney cortex from *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice after 6 weeks of ANG II. (E) Representative transmission electron micrographs of glomeruli from *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} at 6 weeks. The * highlights an area of podocyte foot process effacement and fusion in *Ednrb*^{lox/lox} mice and an area of normal podocyte ultrastructure in LysM-Cre *Ednrb*^{lox/lox} mice. (F) Representative images of Masson's trichrome-stained kidney medulla from *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice after 6 weeks of ANG II with (G) associated quantification of tubular casts. (H) RT-qPCR analysis of cortical and medullary *Kim-1* message at baseline and after 6 weeks. Data represent mean \pm SEM of n=10 mice/group. *p <0.05, ***p <0.001 and ****p <0.0001 for baseline compared to week 6 within the same genotype; \$p <0.05 and Ψ p <0.001 for one genotype compared to the other at the same time point. Between group comparisons for normally distributed data were by t-test (C, G) or two-way ANOVA with Sidak post-test of plan comparisons (B, H). For between group comparisons of non-normally distributed variables, a Mann-Whitney test (C) or Kruskal-Wallis test was employed. Scale bar: 20 μ m.

Figure 2: Specific deletion of Ednrb from myeloid cells reduces ANG II-mediated renal inflammation

Representative images of renal (A) F4/80 and (B) CD3 staining on kidney sections from *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice at baseline and after 6 weeks of ANG II infusion.

Data represent mean \pm SEM of n=8 mice/group. **p<0.01 for one genotype compared to the other. Between group comparisons were made by un-paired t-test. Scale bar: 20 μ m.

Figure 3: Specific deletion of Ednrb from myeloid cells promotes an anti-inflammatory renal environment in response to ANG II

RT-qPCR analysis of renal cortex and medulla of *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice before and after 6 weeks of ANG II. Data represent mean \pm SEM fold change from baseline; n=7 mice/group. *p <0.05 for baseline compared to week 6 within the same genotype; \$p <0.05 for one genotype compared to the other at the same time point. Comparisons were made by two-way ANOVA with Sidak post test for planned comparisons.

Figure 4: Specific deletion of Ednrb from myeloid cells protects from ANG II-mediated retinal injury

All data are following 6 weeks of ANG II. (A) Quantification of retinal hemorrhagic spots in *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice. (B) Representative images of inner retina vascular network stained with lectin from *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice. Vascular network density was calculated from an average of 4 images/retina using the NeuronJ plugin on ImageJ software. (C) Representative images of microglia within the inner retina stained with iba-1 antibody from *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice. Activated microglia, which have an amoeboid morphology with a large cell body and short neurites (*), were counted from 4 images/retina. Data represent mean \pm SEM; n=5 mice per group. *p <0.05 and **p<0.01 for one genotype compared to the other. Between group comparisons were performed with a Mann-Whitney test. Scale bar: 50 μ m

Figure 5: Specific deletion of Ednrb from myeloid cells does not affect ANG II-mediated cardiac injury

Effects on (A) heart rate, (B) cardiac output, (C) fractional shortening, (D) renal artery blood flow, (E) basilar artery blood flow and (F) basilar artery vascular function at baseline and following 6 weeks of ANG II in *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice. Data represent mean \pm SEM of n=8 mice/group. *p <0.05, **p <0.01; ***p <0.001 for baseline compared to week 6 within the same genotype; \$p <0.05 for one genotype compared to the other at the same time point. Comparisons were made by two-way ANOVA with Sidak post test for planned comparisons.

Figure 6: Specific deletion of Ednrb from myeloid cells protects from ANG II-mediated endothelial dysfunction

Endothelium-dependent (acetylcholine) and endothelium-independent (sodium nitroprusside) vascular function in *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice at baseline and following 6 weeks of ANG II. Data represent mean \pm SEM of n=8 mice/group. Between group comparisons were performed with a two-way ANOVA.

Figure 7: Specific deletion of Ednrb from myeloid cells has a biphasic effect on the BP response to ANG II and promotes long-term natriuresis

(A) Systolic and diastolic BP of *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice during 6 weeks of ANG II infusion. (B) urinary sodium excretion over this 6-week period. (C) Expression of cortical and medullary α ENaC and ET_B receptor in *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice at baseline and following 6 weeks of ANG II. Data represent mean \pm SEM of n=5-7 mice/group. *p <0.05 and ***p <0.001 for baseline compared to week 6 within the same genotype; \$p <0.05 for one genotype compared to the other at the same time point. Between group comparisons were performed with two-way ANOVA.

Figure 8: Specific deletion of Ednrb from myeloid cells promotes an anti-inflammatory macrophage phenotype in response to ANG II

Peritoneal macrophages were harvested from *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice after 6 weeks of ANG II. (A) a range of M1 macrophage markers and (B) cytokines were assessed following stimulation with LPS/INF γ ; (C) M2 markers were assessed following stimulation with IL4/IL13; (D) phagocytosis. Data are mean \pm SEM; n=6/group. *p <0.05, **p <0.01 and ***p < 0.001 for one genotype compared to the other. Between group comparisons were performed with a one-way ANOVA with Sidak post test for planned comparisons..

Figure 9: Specific deletion of Ednrb from myeloid cells promotes a less inflammatory neutrophil phenotype in response to ANG II

Bone marrow derived neutrophils from *Ednrb*^{lox/lox} and LysM-Cre *Ednrb*^{lox/lox} mice were cultured *in vitro* after 6 weeks of ANG II. (A) TNF α and (B) IL6 production following stimulation with LPS. Data are mean \pm SEM; n=5/group. *p <0.05 for baseline compared to week 6 within the same genotype; \$p <0.05 for one genotype compared to the other at the same time point. Comparisons were made by two-way ANOVA with Sidak post test for planned comparisons.

Figure 1

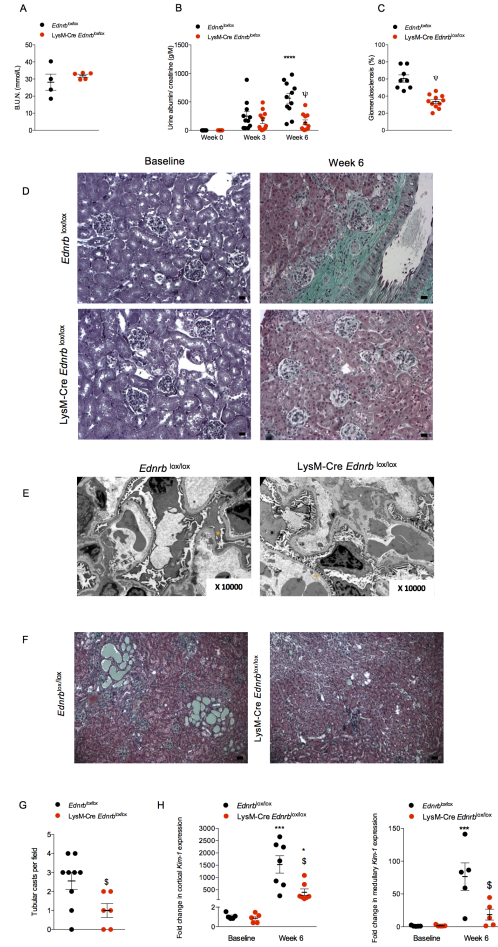


Figure 2

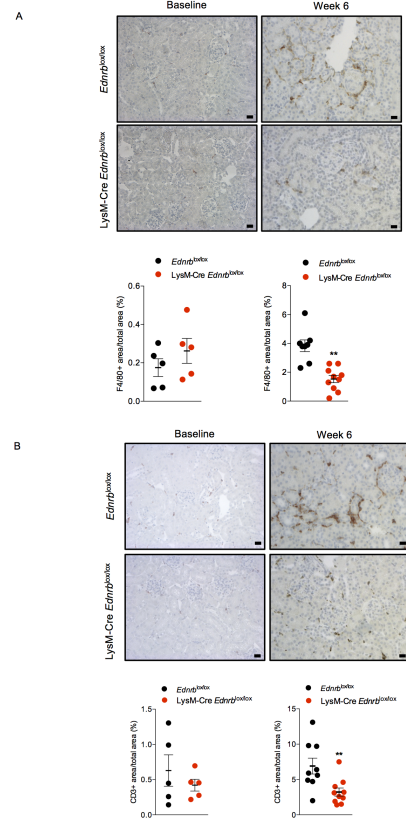


Figure 3

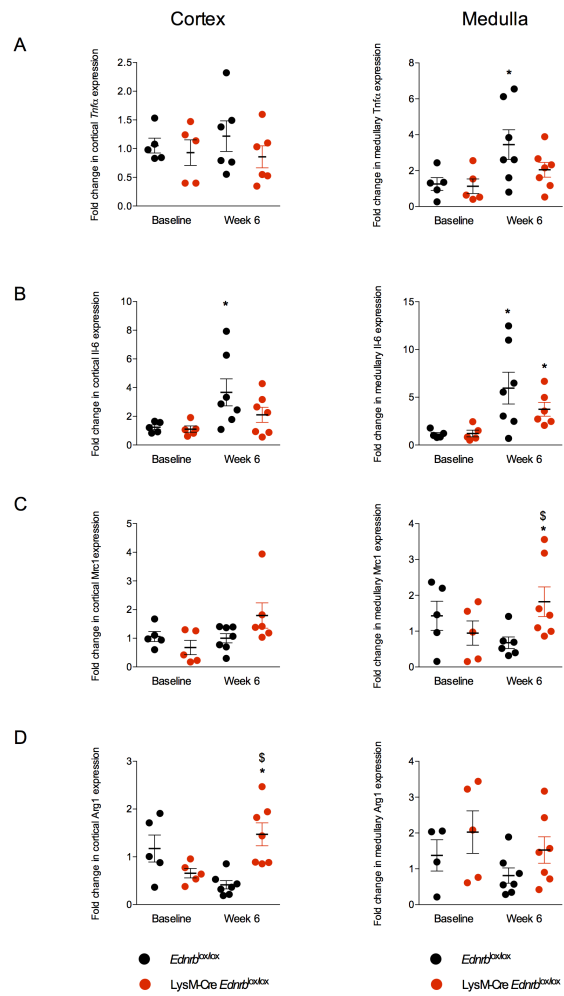


Figure 4

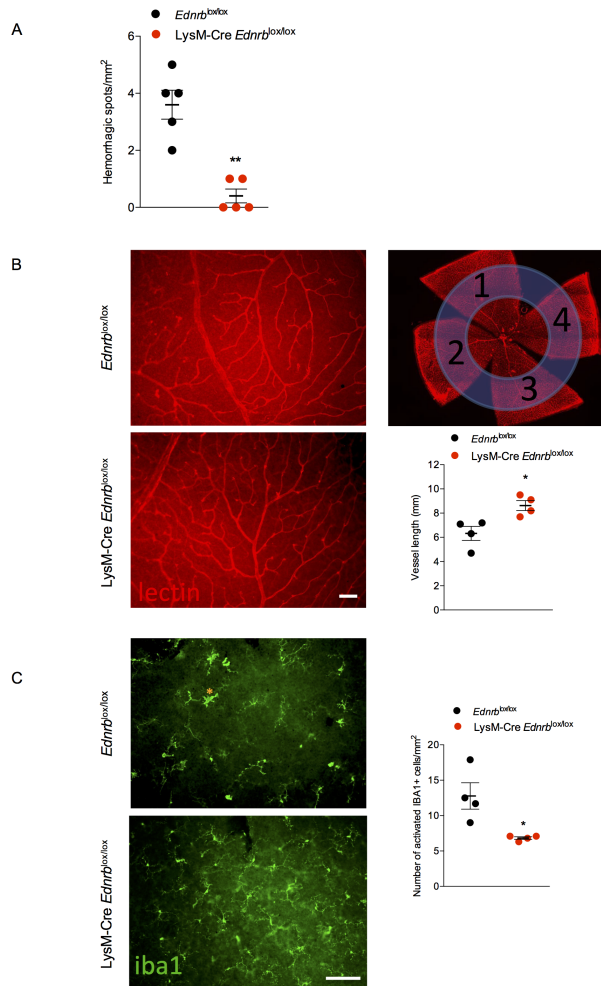


Figure 5

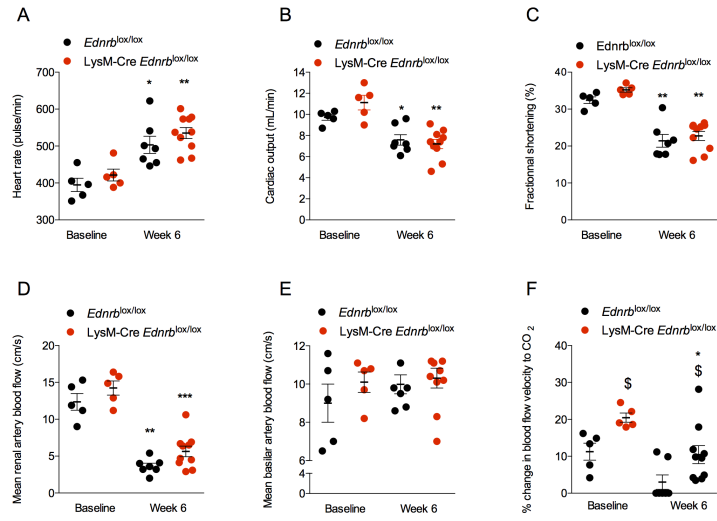


Figure 6

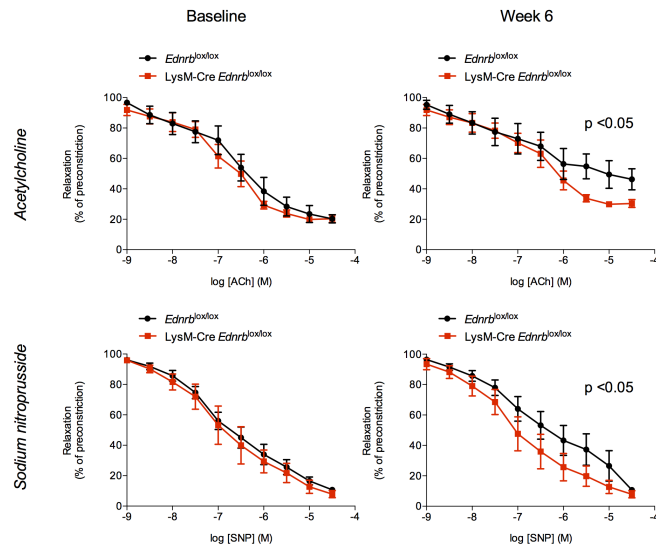


Figure 7

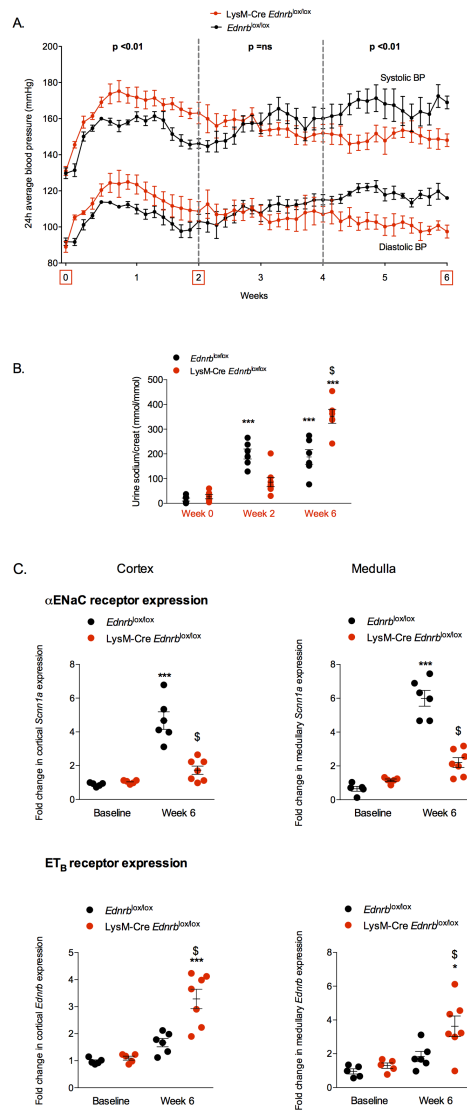


Figure 8

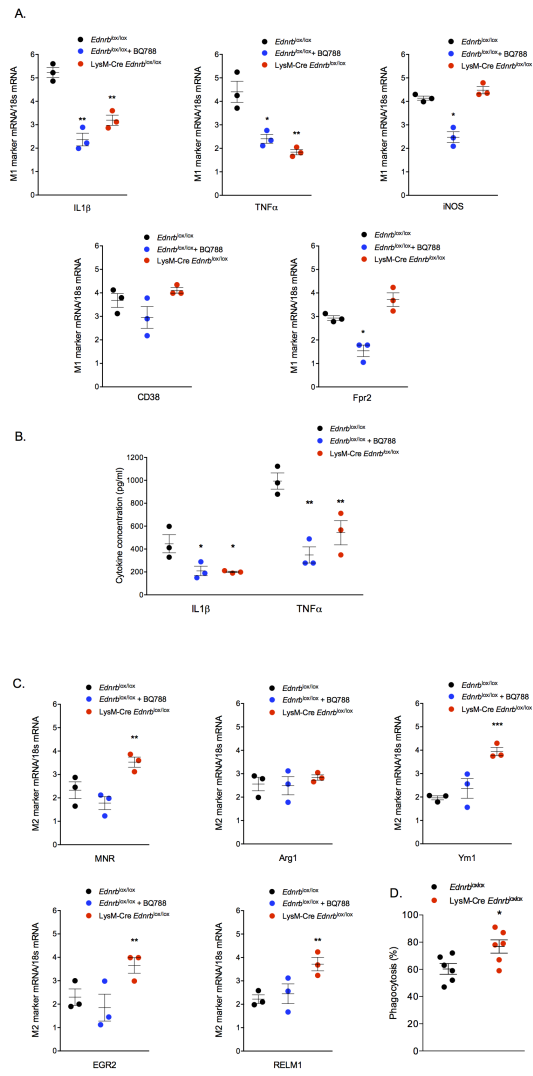


Figure 9

